Heat Generation by Siliceous Igneous Rocks of the Basement and its possible influence on Coal Rank in the Sydney Basin, New South Wales

R. A. FACER, A. C. HUTTON and D. J. FROST

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The Sydney Basin rests unconformably along its northwestern, western and southern margins on rocks of the Lachlan Fold Belt. Devonian and Carboniferous siliceous igneous rocks, which comprise approximately 25% of this basement, have been sampled at 18 sites — from Gulgong in the north to Moruya in the south — for this investigation.

On the basis of chemical data (SiO_2, K_2O and trace elements) here, the Carboniferous rocks can be distinguished from the Devonian rocks. New heat-generation values, based on K-, Th- and U-contents, have been determined for the 18 sites, together with calculations based on published chemical data from 5 localities (including one of the new sites). The new determinations agree with previously-published heat-generation data for the Bathurst batholith and Moruya Tonalite. Heat generation (mean) by the Carboniferous rocks, with the Nelligen Granodiorite included because of its chemical similarities to the other Carboniferous rocks, is relatively high at 2.53 $\mu W/m^3$ (n = 13, s.d. = 0.46 $\mu W/m^3$). Heat generation (mean) by the Devonian rocks is 1.98 $\mu W/m^3$ (n = 9, s.d.=0.39 $\mu W/m^3$).

Variation in heat generation in the basement to the Sydney Basin may be an important influence in the flow of heat through the basin. Together with influences by rocks within the basin, heat generation is a potential long-term influence on rank of the coal in the Permian Illawarra Coal Measures in the western and southern portions of the Sydney basin.

R. A. Facer, A. C. Hutton and D. J. Frost, Department of Geology, University of Wollongong, P.O. Box 1144, Wollongong, Australia 2500; *manuscript received 10 November 1978, accepted in revised form 19 September 1979.*

INTRODUCTION

The northern and northeastern portions of the Sydney Basin consist of a sequence of Carboniferous volcanic rocks which passes up into Permian and then Triassic sequences. Apart from very minor patches of Carboniferous sedimentary rocks, the basal rocks of the Sydney Basin sequence at its western and southern edges are Permian in age, and unconformably overlap Palaeozoic rocks (Fig. 1) of the Lachlan Fold Belt. Included in the basement rocks are siliceous igneous rocks — both extrusive and intrusive (cf. various discussions *in* Packham, 1969).

Heat generation in rocks of the Bathurst batholith is (relatively) high (Bunker *et al.,* 1975; Facer, 1977). Sass *et al.* (1976) showed that heat flow through the Sydney Basin is apparently higher than other areas of eastern Australia, and suggested a possible relation to Tertiary extrusive rocks on the southwestern Sydney Basin. The thermal history of the basin, including heat generation and the timing of thermal events, is an important problem in understanding the rank of coal in the Sydney Basin (cf. Facer *et al.,* 1978). White *et al.* (1974) have noted high heat flow in the rocks of the Lachlan Fold Belt.

This study was carried out to assess the heat generation by siliceous igneous rocks from the basement along the northwestern to southern margin of the Sydney Basin. Data obtained will provide background information for detailed investigation of the

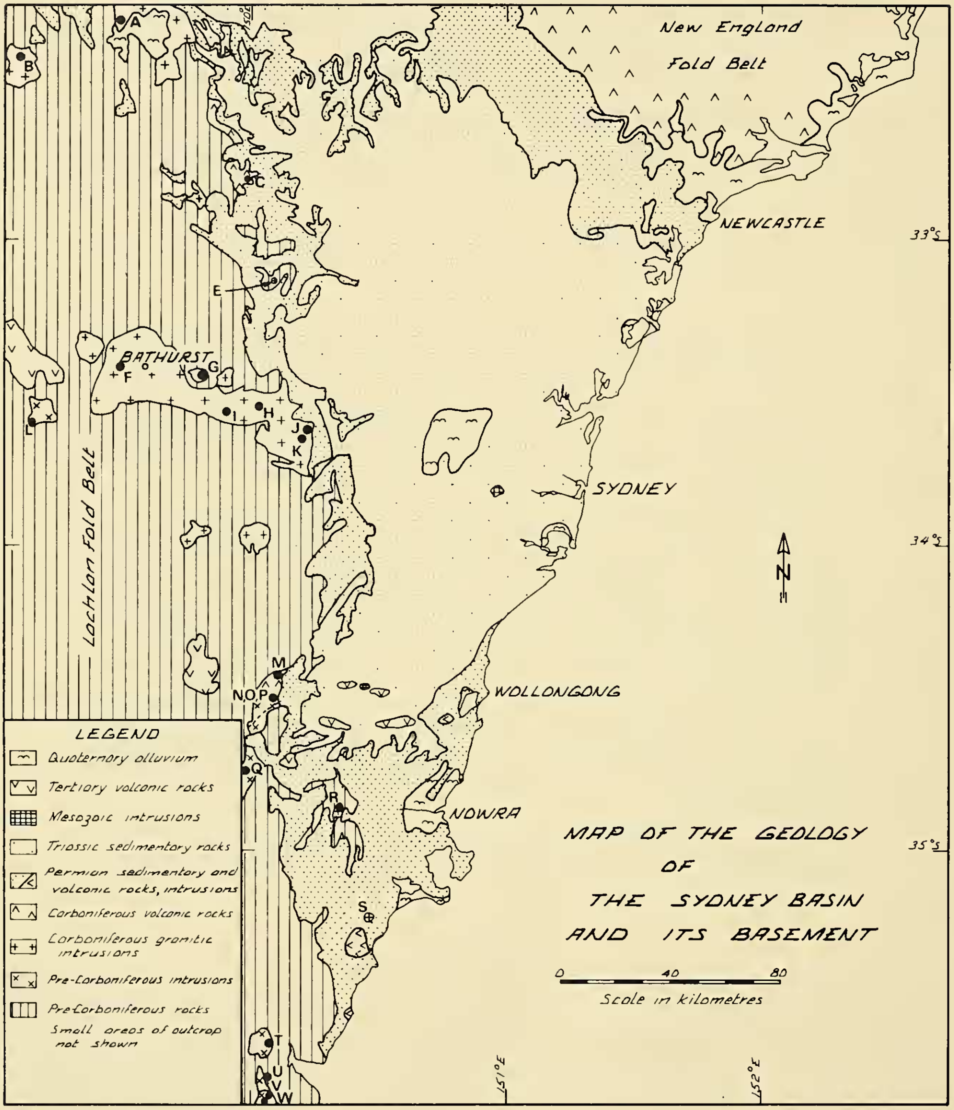

Fig. 1. Map of Sydney Basin

thermal setting of the Sydney Basin — to assist in understanding the rank of the Permian coal (and variations in its rank) within the basin. Samples have been collected from the intrusive and extrusive igneous basement rocks along the northwestern, western and southern edges of the basin. These rocks constitute approximately 25 per cent of the exposed basement. All the major siliceous bodies have been sampled, as well as some of the smaller intrusions or exposures (for example the "windows" of granitic rocks at Yalwal and Gooloo Creek, sites R and S in Fig. 1). Mafic rocks and deeply weathered rocks have not been analysed. Because of present inadequate knowledge on the behaviour of Th and U in metamorphic reactions (Rogers and Adams, 1969*a*, *b*) the metamorphosed pre-Carboniferous volcanic and sedimentary rocks were not sampled for this phase of the overall investigation.

TABLE 1

Ages of the Sydney Basin basement rocks for which heat generation data are presented herein

Locality (1)	Rock unit	Age(2)	Reference for Age
A	Gulgong Granite	312 My	Evernden and Richards(1962)
B	Wuuluman adamellite	Carb.	Brunker and Rose (1969)
C	Rylstone (dacite) tuff	Carb.	Day (1969)
D	Yeoval batholith	ca 392 My	Gulson and Bofinger (1972)
E	Huntingdale "rhyolite"	Carb. (?Dev.)	Brunker and Rose (1969)
F	Dunkeld adamellite	303 ± 2 My	Facer (1978)
G	Durandal Adamellite	314 ± 6 My	Facer (1976)
H	Sodwalls adamellite	Carb.	Vallance (1969)
I	Carlwood granite	Carb.	Vallance (1969)
J	Hartley adamellite	311 ± 6 My	Evernden and Richards (1962)
K	Hartley granodiorite	(?) 311 My	cf. Rhodes (1969)
L	Carcoar Granite	Dev. (?Carb.)	Brunker and Rose (1969); Vallance (1969)
M	Yerranderie rhyodacite	Dev.	Jones *et al*. (1977)
N	Bindook Porphyry	Dev.	This investigation
O	Jemidee granodiorite	Dev.	This investigation
P	Mandari granodiorite	Dev.	This investigation
Q	Marulan Granite	Dev.	Felton (1974)
R	Bundundah granite	Carb.	Vallance (1969); McIlveen (1975)
S	Gooloo granite	Carb.	McIlveen (1975)
T	Nelligen Granodiorite	Dev.(?) (3)	Chappell and White (1976)
U	Minor intrusions (Moruya)	Dev.	Chappell and White (1976)
V	Moruya batholith	381 ± 3 My	Chappell and White (1976)
W	Moruya tonalite	(?) 381 ± 3 My	Chappell and White (1976)

Notes: (1) Locality — the code corresponds to the localities given in Fig. 1.
(2) Age — the radiometric ages have been recalculated where necessary to correspond to the decay constants given in Steiger and Jager (1977). Recalculations for entries G and J are from Facer (1978). Entry D assumed a mean age before recalculation of 400 My. Errors for entries F (2 values), G(4), J(2), and V and W(3) are standard deviations of the mean recalculated ages. The abbreviations are Dev. (Devonian) and Carb. (Carboniferous).
(3) The age for the Nelligen Granodiorite may be Carboniferous, (based on chemical data.

However, sampling of these rocks for a more complex investigation of K, Th and U distribution has commenced. The mafic phases of the Bathurst batholith comprise only a minor proportion of that complex. Rocks of the Sydney Basin rest on deeply weathered "granite" at unsampled localities, such as the Aaron's Pass granite contact 20 km south of Rylstone (site C in Fig. 1). In such rocks leaching may have redistributed heat-generating elements, especially uranium, and hence the surface material would not give a true value for heat generation. Where possible artificial exposures such as road cuts, blasted sites and drill core were sampled.

Because no published chemical data could be found for many of the newly-

TABLE 2

Chemical analyses of some (igneous) basement rocks along the northwestern to southern margins of the Sydney Basin

Analysis	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Locality	A	B	B	C	E	F	G	G	H	I	J	L	M	N	N	O	P	Q	R	R	R	R	S	W
Age	C	C	C	C	C(?)	C	C	C	C	C	C	D(?)	D	D	D	D	D	D	C	C	C	C	C	D
Oxide weight percentages																								
SiO_2	68.94	66.91	67.15	64.50	76.49	66.51	68.56	70.81	75.29	74.76	72.21	64.76	67.20	65.58	66.78	67.66	67.84	69.39	74.64	75.02	74.68	76.78	74.41	62.56
TiO_2	0.48	0.54	0.58	0.56	0.18	0.54	0.48	0.19	0.13	0.24	0.35	0.53	0.53	0.63	0.55	0.54	0.53	0.43	0.12	0.14	0.16	0.11	0.11	0.98
Al_2O_3	14.89	15.30	14.59	15.49	12.38	15.53	14.87	16.15	12.97	13.38	13.99	14.72	14.00	15.29	15.50	14.22	14.67	14.88	10.68	12.62	13.15	11.75	13.25	15.94
Fe_2O_3	1.52	0.90	1.37	1.29	0.29	0.96	0.96	1.83	0.18	0.37	0.72	0.26	0.38	1.51	0.98	1.23	0.61	1.17	1.62	0.07	1.04	0.52	0.32	2.85
FeO	1.58	2.02	1.75	1.90	1.37	2.92	2.24		0.90	1.05	1.53	5.07	3.63	3.71	3.53	3.35	2.99	2.10	3.28	2.11	0.68	0.84	1.35	2.96
MnO	0.09	0.05	0.06	0.10	0.02	0.07	0.07	n.d.	0.03	0.04	0.05	0.09	0.07	0.08	0.07	0.07	0.05	0.05	0.30	0.12	0.07	0.06	0.04	0.07
MgO	1.31	1.63	1.77	1.08	0.50	1.98	1.18	0.50	0.42	0.44	0.81	3.19	2.03	2.49	1.91	1.89	1.79	1.06	0.31	0.12	0.09	0.06	0.27	2.68
CaO	2.76	2.62	2.62	3.39	0.23	3.96	2.83	1.32	1.26	1.08	1.78	5.30	1.82	4.47	5.03	4.20	3.48	3.71	0.24	0.55	0.49	0.51	1.07	5.10
Na_2O	3.82	3.89	4.20	3.17	2.95	3.25	3.85	3.21	2.73	3.55	3.29	2.39	3.12	2.12	2.49	2.09	3.42	2.80	1.67	3.10	3.52	3.49	4.30	3.92
K_2O	3.47	4.78	3.94	3.61	4.36	3.44	3.50	4.54	5.46	5.01	4.38	1.99	4.42	2.79	2.88	2.98	2.93	3.46	3.80	4.66	4.84	4.43	3.30	1.79
H_2O^+	n.d.	n.d.	0.84	n.d.	n.d.	n.d.	1.16	-	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.68	n.d.
H_2O^-	n.d.	n.d.	0.23	n.d.	n.d.	n.d.	0.25	-	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.12	n.d.
P_2O_5	0.20	0.25	0.28	0.18	0.05	0.18	0.17	0.12	0.04	0.04	0.12	0.11	0.13	0.15	0.13	0.12	0.15	0.11	0.03	<0.02	<0.02	<0.02	0.04	0.29
CO_2	n.d.	n.d.	0.04	n.d.	n.d.	n.d.	-	-	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
L.O.I.	0.76	0.55	n.d.	4.96	1.46	0.36	n.d.	n.d.	0.74	0.38	0.86	0.95	2.59	1.08	0.27	0.90	0.95	0.82	3.59	1.65	1.02	0.90	n.d.	0.66
TOTAL	99.82	99.44	99.42	100.23	100.28	99.70	100.12	98.67	100.15	100.34	100.09	99.36	99.92	99.90	100.12	99.25	99.41	99.98	100.28	(100.16)	(99.74)	(99.45)	99.26	100.41
S.G.	2.66	(2.68)		2.54	2.65	2.70	(2.67)		2.61	2.61	2.64	2.68	2.75	(2.74)		2.69	2.72	2.68	2.75	2.61	(2.60)		2.62	2.76
Trace elements (ppm)																								
V	61.2	52.0	n.d.	55.3	18.2	97.4	n.d.	n.d.	18.3	10.7	29.0	132.0	65.0	111.	108.	112.	63.2	39.7	18.3	5.8	5.8	5.8	n.d.	105.
Co	9.8	8.0	n.d.	8.3	4.7	13.0	n.d.	n.d.	14.6	4.7	5.7	20.2	12.3	12.0	11.1	14.6	11.8	8.1	9.0	3.3	2.8	1.9	n.d.	18.8
Ni	10.9	17.8	n.d.	6.2	8.9	18.7	n.d.	n.d.	7.3	9.0	8.9	23.8	13.3	15.3	13.7	14.9	16.6	11.9	14.3	12.0	7.9	10.5	n.d.	18.7
Cu	5.1	7.0	n.d.	3.8	2.6	4.3	n.d.	n.d.	2.2	2.6	2.7	25.1	3.8	9.1	10.3	9.3	8.3	6.1	1160.	78.7	14.0	2.2	n.d.	13.6
Zn	61.7	52.0	n.d.	76.8	54.8	59.0	n.d.	n.d.	17.8	36.1	38.0	73.5	74.0	65.8	53.9	50.0	53.0	60.1	1310.	15.8	99.9	26.2	n.d.	75.5
Cd	0.1	<0.1	n.d.	0.15	<0.1	<0.1	n.d.	n.d.	<0.1	(0.15)	0.13	0.1	0.1	<0.1	0.24	<0.1	0.1	0.39	8.6	1.2	0.19	0.1	n.d.	0.1
Pb	12.0	10.3	n.d.	12.4	53.6	59.0	n.d.	n.d.	7.6	15.4	10.4	21.9	13.3	20.6	24.3	21.8	14.6	24.4	1050.0	42.8	16.1	8.0	n.d.	14.0

sampled rocks whole rock analyses were also carried out. These data were also used for comparison between rock bodies.

REGIONAL GEOLOGY

Fig. 1 shows the sites which provided fresh samples for this investigation. In addition, data from an area near Yeoval (32° 45′ S, 148° 40′ E), sampled by Gulson (1972), have been included as site D. Table 1 indicates the ages of the rocks used in this investigation, although no radiometric age data are available for many sites. All the granitic rocks are "massive", and most are of the Bathurst-type association (Vallance, 1969). Similarly the extrusive rocks show evidence of only minor deformation in thin section, although they have been folded with meridional trends. The intrusive rocks have been emplaced into Ordovician to Devonian metamorphosed sedimentary and mafic extrusive rocks of the Lachlan Fold Belt (Packham, 1969).

Outcrops of the Devonian granitic rocks follow the regional meridional trends, although adjacent to the Sydney Basin such trends were apparently not imposed by post-emplacement tectonic activity. The Carboniferous granitic rocks along the Basin margins cut across the trends of the older rocks. Both Devonian and Carboniferous granitic intrusive rocks have mineralogical and chemical affinities with — and thus apparent genetic relationships to — adjacent extrusive rocks, such as near Bullio and Yerranderie (localities M, N, O, P in Fig. 1), and near Rylstone (Day, 1969) (locality C).

Chappell and White (1974, 1976) recognized two types of granitic rocks in the Lachlan Fold Belt. These two types are distinguished using chemical criteria, and have been interpreted to indicate two different types of source material — I-type from igneous material and S-type from sedimentary material (Chappell and White, 1974).

PETROGRAPHIC AND CHEMICAL DATA

New chemical data are presented here for 18 of the localities of Table 1 and Fig. 1, although chemical data have previously been published for some of the sites. Analyses for major oxides and some trace elements are listed in Table 2. Table 3 contains new results of analyses for Th and U for 18 sites, and also summarizes published K, Th and U data for 5 sites.

PETROGRAPHY

Petrographic descriptions for the samples analysed in this investigation are summarized in Appendix 1. The descriptions are based on both thin section and polished section study. The adamellite from Hartley has been described in detail by Joplin (1931), whose data are supplemented by new observations here.

The Gooloo granite (analysis 23 in Table 2) is a small inlier of granite exposed in Gooloo Creek and possibly also in Conjola Creek (McIlveen, 1974; 1975). Roadworks

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TABLE 2 (Continued)

NOTES: The locality code corresponds to Table 1 and Fig. 1. Grid localities are for the (named) 1:250,000 map sheets. Sample numbers refer to the University of Wollongong reference collection. In some cases the specific gravity has been averaged for a locality.
n.d. - not determined. Ages are given as Carboniferous (C) or Devonian (D).
Major oxide analyses (XRF) were by R.H. Flood and S.E. Shaw, except analyses 7 and 8 (I.R. Plimer *in* Facer, 1977, table 2), and 23 (AMDEL).
Trace element analyses (AAS) by A.M. Depers.

1. R7571. Small quarry (several blocks), Dubbo 243001.
2. R6619. Roadworks (several blocks), Dubbo 206988
3. (Anal. 3 supplied by E.R. Phillips) (locality near that for 2).
4. R7585. Roadworks (2 blocks), Dubbo 295946.
5. R7574. Natural outcrop, Sydney 312904.
6. R6631. Road cutting (several blocks), Bathurst 245871.
7. Facer (1977, table 2, 1 and 5) A dash indicates n.d. for one sample.
8. Facer (1977, table 2, 2 and 3) Roadworks and cutting, Bathurst 277866.
9. R6621. Roadworks (2 blocks), Sydney 300857.
10. R6624. "Opera House Quarry", average of two analyses, Bathurst 285850.
11. R6626 and R7578. Roadworks, average of two analyses, Sydney 315855.
12. R6620. Roadworks, Bathurst 213846.
13. R7573. Drill core, 209m depth, Wollongong 321784(approx.).
14. R7235. Pulpit Rock member of Bindook Porphyry, natural outcrop, Wollongong 317757.
15. R7236. Rileys Range member of Bindook Porphyry, natural outcrop, Wollongong 316758.
16. R7237. Natural outcrop, Wollongong 314757.
17. R7238. Natural outcrop, Wollongong 318753.
18. R7575 and R7576, Roadworks, average of two analyses, Goulburn 294696.
19. R6695. Altered vein, natural outcrop, Wollongong 339690.
20. R6697A. At altered vein, natural outcrop, Wollongong 339690.
21. R6697B. 10cm from altered vein, natural outcrop, Wollongong 339690.
22. R6696. 3m from altered vein, natural outcrop, Wollongong 339690.
23. R7581. Roadworks (2 blocks), Ulladulla 344651.
24. R6472. Roadworks (several blocks), Ulladulla 311564.

TABLE 3

Heat generation of some (igneous) basement rocks along the northwestern to southern margins of the Sydney Basin

Locality	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
Age	C	C	C	D	C(?)	C	C	C	C	C	C	D(?)	D	D	D	D	D	C	C	C/D	D	D	D
Chemical data																							
K(%)	2.88	3.62	3.00	3.32	3.62	2.86	3.34	4.53	4.16	3.64	3.00	1.65	3.67	2.35	2.47	2.43	2.87	3.85	2.74	2.91	1.82	1.71	1.49
Th(ppm)	14.2	15.4	18.0	15.4	21.1	13.8	19.2	15.1	18.5	19.5	19.6	13.9	15.6	14.4	14.8	14.1	13.5	15.3	14	15.4	8.8	8.7	13.7
U(ppm)	2.9	2.9	4.8	3.5	3.7	3.3	6.0	4.1	4.4	5.1	4.9	2.8	4.1	3.1	2.9	3.4	2.9	3.0	1.7	5.3	2.0	2.1	2.9
S.G.	2.66	2.68	2.54	2.67*	2.65	2.70	2.67	2.61	2.61	2.64	2.69	2.68	2.75	2.74	2.69	2.72	2.68	2.60	2.62	2.76*	2.76*	2.76*	2.76
Heat generation (Bunker *et al.*, 1975, equation, p.2)																							
10^{-13}cal/cm^{3}sec	4.83	5.24	6.37	5.53	6.63	5.08	7.72	5.98	6.65	7.20	7.08	4.47	6.19	5.02	4.90	5.13	4.75	5.18	3.97	6.76	3.25	3.27	4.60
µW/m^3	2.02	2.19	2.66	2.31	2.77	2.12	3.23	2.50	2.78	3.01	2.96	1.87	2.59	2.10	2.05	2.14	1.99	2.17	1.66	2.83	1.36	1.37	1.92
Heat generation (Rybach, 1976, equation 3, p.311)																							
µW/m^3	1.97	2.13	2.59	2.25	2.70	2.07	3.14	2.44	2.70	2.93	2.88	1.82	2.52	2.04	1.99	2.09	1.93	2.11	1.61	2.76	1.32	1.32	1.87

NOTES: In some cases "rounding" during averaging has been necessary, but care was taken to ensure that cumulative errors did not increase the value of the heat generation. (This rounding was necessary to maintain consistency of significant figures in chemical data.) The chemical information for K is based on Table 2, and on the references given in the listing below. Analyses for Th and U for this investigation were carried out by A. Holland, following the technique of Pollock (1977), except for S (Th by XRF and U by fluorimetry; anal. AMDEL).

* - signifies that the specific gravity is estimated here.

A	Table 2, analysis 1.
B	Table 2, analyses 2 and 3 (Th,U: 1 anal.)
C	Table 2, analysis 4.
D	Gulson (1972, average of table 3: granodiorite, 3 analyses; and table 4 granite, 4 analyses)
E	Table 2, analysis 5.
F	Table 2, analysis 6.
G	Table 2, analyses 7 and 8 (Th and U, 3 analyses).
H	Table 2, analysis 9.
I	Table 2, analysis 10.
J	Table 2, analysis 11.
K	Rhodes (1969 table 3, average, 9 anals).
L	Table 2, analysis 12.
M	Table 2, analysis 13.
N	Table 2, analyses 14 and 15.
O	Table 2, analysis 16.
P	Table 2, analysis 17.
Q	Table 2, analysis 18.
R	Table 2, analyses 21 and 22.
S	Table 2, analysis 23.
T	Griffin *et al.* (1978, table I, analyses MG1 to MG3).
U	Griffin *et al.* (1978, table I, analyses MG5 to MG8, MG15, MG22).
V	Griffin *et al.* (1978, table I, analyses MG9 to MG14).
W	Table 2, analysis 24.

at Gooloo Creek indicate an unconformable relationship between the Gooloo granite and the Sydney Basin. The name Bundundah granite is used here for the "Bundundah Porphyritic Microgranite" referred to by McIlveen (1975, p. 6) and based on mapping of granite in the Bundundah, Yarramunmun, Danjera and Yalwal Creeks area (Towey, 1965; Wall, 1965; Frost, 1977). Like the Gooloo granite the Bundundah granite is overlain by Sydney Basin rocks, but the Devonian sedimentary and volcanic rocks into which it is emplaced are also exposed.

CHEMISTRY

The chemical data in Table 2 indicate that all the rocks analysed are silica-rich, no granites (*sensu lato*) containing less than about 65% SiO_2. The tonalite of analysis 24 is marginally less siliceous than the other rocks, but this analysis is similar to those of Griffin *et al.* (1978, table 1) for the Moruya Tonalite. Allowing for slightly different sample-sites, degree of weathering and techniques, analysis 11 is similar to analyses IX and X of Joplin (1931, p.53).

The Carboniferous rocks are generally more siliceous than the Devonian samples, but detailed comparisons would require more accurate age data. As indicated in Table 1 some sites have not been dated by radiometric techniques — in which case their most likely age is indicated.

Chemical analyses for the Bundundah granite of site R (Table 2, analyses 19 to 22; with petrographic descriptions in Appendix 1) indicate that the distribution of major oxides in the two phases of the granite differs from that in the hydrothermally altered zone in Fe content and oxidation state, Na_2O and Al_2O_3. Co, Cu, Cd and Pb increase markedly towards the altered zone. In addition, Th (23.1 ppm) and U (6.3 ppm) are high in the vein (cf. Table 3, entry R for Th and U content away from the vein). These increases apparently indicate that hydrothermal solutions have introduced trace metals, including Th and U, and hence only analyses 21 and 22 (Table 2) have been used for heat-generation calculations.

HEAT GENERATION

An indication of the generation of heat by the heat-producing elements in rocks is provided by the equation (after Bunker *et al.*, 1975):

Heat Generation

$$= [(0.27K\% + 0.20Th\ ppm + 0.73U\ ppm) \times \frac{S.G.}{3.156}] \times 0.418\,\mu W/m^3 \qquad (1)$$

(1 heat-generation unit (HGU)) is 10^{-13} cal/cm³sec = 0.418 $\mu W/m^3$). Equation 1 is similar to that given by Rybach (1976, equation 3, p.311), who also gave details of the decay processes giving rise to the heat generation. Isotopic equilibrium is assumed when using such an equation.

Values of heat generation obtained using equation 1 (Table 3) average 1.028 times those determined using Rybach's (1976) equation. However, as equation 1 follows the decay data in Rogers and Adams (1969*b*, p.92-B-2), and as much published heat generation information has been published using these decay data comparison will be facilitated by adopting them.

Discussion here will be based on determinations using equation 1. Some of the determinations in Table 3 are for rocks which outcrop beyond the present margin of the basin, but near outliers of Permian sedimentary rocks (such as Wuuluman, site b, cf. Dulhunty, 1964) — or as major rock bodies which may have a significant influence on basement heat generation (such as Carcoar). Table 3 also contains chemical data for sites D, K, T, U and V, for which no calculations of heat generation were published with the data. The information in Table 3 for the Durandal Adamellite is modified from Facer (1977) using additional data.

Bunker *et al.* (1975) have presented heat-generation data for the Bathurst batholith (although the last entry in their table 2-2 should be located at (33° 24′ S, 149° 20′ E), one site in schist from Apsley (33° 34′ S, 149° 34′ E); and one site from the Moruya batholith. The data of Bunker *et al.* (1975) have been converted into heat-generation units using S.G.'s of 2.65 (based on measurements of other samples) for the Bathurst batholith and 2.60 for Apsley schist, and by converting data from Sass *et al.* (1976, p.13) for the Moruya batholith. These recalculated data are:

Bathurst batholith — 3.02 μW/m^3;
Apsley schist — 2.44 μW/m^3; and
Moruya batholith — 1.45 μW/m^3.

Heat-generation values determined by Bunker *et al.* (1975), recalculated here, for the Bathurst batholith agree well with those of the present investigation in Table 4. Similarly, for the Moruya batholith the mean (Table 4) agrees with that of Bunker *et al.* (1975).

Heat generation in the Nelligen Granodiorite (entry T in Table 3) is approximately twice that in the minor intrusions (Table 3, U) adjacent to the main mass of the Moruya Tonalite and the tonalite (Table 3, V and W). Entry U of Table 3 includes data for a "gabbroic diorite" phase of the Mogendoura Granodiorite (Griffin *et al.,* 1978, p.238 and table 1), although exclusion of this mafic phase would only raise the value of the heat generation to 1.57 μW/m^3 — still only about half that for the Nelligen Granodiorite.

The mean heat generation for all 22 values based on equation 1 (Table 4) is 2.31

TABLE 4

Mean heat generation in siliceous igneous rocks in the basement to the Sydney Basin

Igneous rocks mass or group of rocks	Number of analyses	Heat generation μW/m^3 mean	s.d.	Entries in Table 3
Bathurst batholith	6	2.77	0.40	F to K
Carboniferous rocks	12	2.51	0.47	A to C, E to K, R and S
Carboniferous rocks and Nelligen Granodiorite	13	2.53	0.46	A to C, E to K, R to T
Moruya batholith	2*	1.41	-	U to W
Devonian rocks	9	1.98	0.39	D, L to Q, U to W
Devonian rocks and Nelligen Granodiorite	10*	2.07	0.46	D, L to Q, T to W
All rocks	22*	2.31	0.51	All
All rocks, except Bathurst batholith	17*	2.13	0.44	A to E, L to W

Note: The entries marked * include a mean value for V and W of 1.46 μW/m^3.

$\mu W/m^3$ (s.d. = 0.51 $\mu W/m^3$). For the 17 values (V and W combined), after omission of entries F to K, the mean is noticeably lower than the mean for the Bathurst batholith (Table 4), although the two values (2.77 $\mu W/m^3$ s.d. = 0.40 $\mu W/m^3$ and 2.13 $\mu W/m^3$, s.d. =0.44 $\mu W/m^3$) are within 2 s.d.'s.

DISCUSSION

The siliceous igneous rocks forming part (25%) of the basement to the Sydney Basin (Table 1) range from Devonian to Carboniferous in age, with the younger rocks outcropping more to the north and the older (Devonian) rocks more to the south of the Bathurst batholith (Fig. 1). Part of the Yeoval batholith may be as old as Late Silurian (Gulson and Bofinger, 1972).

Table 2 indicates that only three of the rocks for which new chemical data are presented contain less than 65% SiO_2. No distinctive chemical differences were noted between intrusive and extrusive rocks. The Carboniferous rocks, especially those of the Bathurst batholith, tend to be more siliceous and potassic than the Devonian rocks. Similarly the Carboniferous intrusions plot slightly towards the A apex on AFM diagrams.

The granites (*sensu lato*) analysed here fit into the I-type classification of Chappell and White (1974) using the first three criteria of their table. However, analysis 8 of Table 2 for the Durandal Adamellite may represent an S-type rock, notwithstanding that analysis 7 fits the I-type classification. There are no apparent mineralogical differences between these adamellite samples sufficient to explain the chemical differences. Aplites and contact adamellite from this site yield an initial $^{87}Sr/^{86}Sr$ ratio of 0.7051 ± 0.0016 (Facer, 1976) which fits one I-type criterion of Chappell and White (1974, p.173). Entry 8 of Table 2 is an average of analyses of different samples by two analysts (cf. Facer, 1977, Table 2), yet has the apparent S-type characteristic of $Mol[Al_2O_3/(Na_2O + K_2O + CaO)] = 1.28$. One possible explanation is that, by coincidence, the analyses 2 and 3 in table 2 of Facer (1977) each contain minor sedimentary xenolithic material which was not observed in the hand specimen blocks prior to crushing, and which was not intersected by thin (or polished) sections. The Durandal Adamellite does contain xenoliths, although those of sedimentary origin are at least subordinate, most having an apparent igneous origin (cf. Mackay, 1964; Facer, 1977). These xenoliths comprise both igneous country rocks (Mackay, 1964) and fragments of a more granitic nature which could have been stoped from the early-cooled parts of the intrusions — and igneous inclusions, some of which may have been assimilated, would tend to suggest an I-type origin.

Th and U contents are generally lower in the older rocks (Table 3). The other trace elements, despite variations, show no strong trends.

The SiO_2, K_2O, Th and U (and to a lesser extent V, Co, Ni and Cu) trends shown by the new analyses and those of Griffin *et al.* (1978, table 1) indicate that the Nelligen Granodiorite may be Carboniferous, and hence not part of the Moruya batholithic complex (cf. McIlveen, 1974; 1975, p.6). Griffin *et al.* (1978, p.244) used chemical data to suggest (qualitatively) a slightly different source for the Nelligen Granodiorite from that for the main Moruya batholith. Several cluster analysis dendrograms were calculated and indicate that results for the Nelligen Granodiorite tend to cluster with the Carboniferous rocks of this investigation. However, lack of complete discrimination between Devonian and Carboniferous rocks precluded definite inclusion of the Nelligen Granodiorite in the Carboniferous group.

The Th and U contents of the Carboniferous rocks (Table 3) are generally at or above the levels listed by Clark *et al.* (1966, figs 24-6 to 24-9) as means and medians for granodiorites (Th 9.3 ppm, 9.0 ppm respectively; U 2.6 ppm, 2.3 ppm respectively) and siliceous igneous rocks (Th 20 ppm, 16 ppm respectively; U 4.7 ppm, 3.9 ppm respectively). For the older rocks of this investigation the Th and U contents are closer to, or below, these averages. However differences between the present calculated means (Table 4) and those of Clark *et al.* (1966) are not marked.

The overall Th:U ratio (with localities V and W combined as one locality) is 4.52 (s.d. = 1.08), not significantly different from the value of 4.0 suggested in fig. 24-13 of Clark *et al.* (1966), and very close to the mean for granitic rocks of 4.63 (s.d. = 0.85) in table 90-E-1 of Rogers and Adams (1969*a*). For the Bathurst batholith this ratio is 3.85 (s.d. = 0.38). For the Bundundah granite the Th:U ratio ranges from 3.67 (for the vein) to 5.50 (10 cm from the vein), with an overall mean of 4.50 (s.d. = 0.85). As this ratio for other samples in Table 3 extends outside the range for the Bundundah granite the introduction of Th and U along the vein does not influence the ratio.

Reflecting the overall K, Th and U content, the heat generation in the Carboniferous rocks, especially in the Bathurst batholith, is higher than in the older rocks. This heat generation is at or above an "average" value for granitic or siliceous igneous rocks based on the data of Clark *et al.* (1966). Although specific isotopes are responsible for production of heat, the heat generation values are based on *total* K, Th and U content (equation 1). The older rocks do not generate less heat than the Carboniferous rocks only because of greater time for radioactive decay. Disequilibrium in the isotopes of K, Th and U could introduce errors in heat-generation studies, for example in analysis of small samples.

Table 4 summarizes the heat-generation data from Table 3, arranged in various groupings — which indicate higher heat generation by the Carboniferous rocks. Because of the possible uncertainty in the age of the Nelligen Granodiorite, the Nelligen data are included in both Carboniferous and Devonian groups. Inclusion of the Nelligen data in the Carboniferous mean makes little change in that mean. Heat generation by the Nelligen Granodiorite is approximately twice that of the Moruya batholith. Although variation in uranium content strongly influences the magnitude of heat generation (and can be redistributed by weathering) all three elements K, Th and U in the Nelligen Granodiorite are closer in content to the Carboniferous rocks than the Devonian rocks. The further work planned on the distribution of K, Th and U may help in the interpretation of the possibly anomalous place of the Nelligen Granodiorite in the sequence of Devonian and Carboniferous intrusions.

The narrow range in S.G.'s of the rocks of this investigation (Table 3) precludes determination of accurate relationships between heat generation, S.G. and seismic velocity (cf. Rybach, 1976). The possible relationship between (high) heat flow and (low) seismic velocity for the Lachlan Fold Belt, discussed by White *et al.* (1974, p.161), may partly reflect the relatively high heat generation in at least some of the siliceous igneous rocks which make up approximately 25% of the fold belt. As yet heat-generation data for the other rocks of the Lachlan Fold Belt are inadequate for discussion of the relationship between heat generation and seismic velocity. The P velocity of 6.52 km/sec reported by Doyle *et al.* (1966) for the layer under the southern and southwestern Sydney Basin corresponds to a low heat generation of approximately 0.8 $\mu W/m^3$ using Rybach's (1976) fig. 2. Thus the relatively "cool" Devonian igneous rocks of this basement may have been emplaced into rocks of even lower heat generation, although the "wedge of a few kilometres of 6 km/sec. material" (Doyle *et al.*, 1966, p. 355) immediately under the basin rocks would correspond to a heat generation of approximately 1.2 $\mu W/m^3$.

Comparatively high heat generation in some basement siliceous igneous rocks may contribute to high heat flow (relative to eastern Australia) within the southern portion (but not the extreme southernmost area) of the Sydney Basin (Munroe *et al.,* 1975; Sass *et al.,* 1976, p.15). However, the lack of heat-flow data from levels below the Triassic rocks of the basin, and the low heat-flow value from near Moruya (Sass *et al.,* 1976), make a detailed thermal properties investigation an interesting problem for research of the present type. The Moruya heat flow may be low partly because the Moruya batholith generates low amounts of heat relative to other granitic rocks of the basement. Although such a programme has commenced, more data are required.

It is apparent that a careful study of variation of heat generation in both basement rocks and the Permian basin rocks needs to be integrated with other criteria of thermal history — such as "coal rank" measurements, even on accessory carbonaceous detritus in the basin rocks. Heat flow, which is partly influenced by heat generation, has an important influence on coal, and may be a significant factor in coal rank variation in the Sydney Basin. The heat which has influenced and still may influence the coal rank was, and is, generated by the basement rocks, as well as rocks below the Illawarra Coal Measures (and within the coal-bearing horizons). The rocks below the coal measures are igneous and sedimentary (including volcanoclastic) rocks. As these igneous rocks are potassium-rich they may be significant contributors to the heat generation — but preliminary data indicate that many of the sedimentary rocks below and within the coal measures also generate more heat than the Moruya batholith. A full investigation of the basement rocks and their distribution (using, for example, gravity surveying) is required. This would help in establishing the relative contribution of basement and basal rocks to the thermal history of the coal within the basin. Such an assessment should assist in evaluating the role of the younger (Jurassic and younger) igneous rocks in and on the basin to the heat flow of the basin. Towards the centre (and northern part) of the Sydney Basin the Carboniferous volcanic rocks may be important generators of heat.

CONCLUSIONS

Analyses of siliceous igneous rocks making up approximately 25% of the basement along the northwestern, western and southern margins of the Sydney Basin have revealed chemical differences between Carboniferous and Devonian rocks. Carboniferous rocks, which tend to outcrop in the northern portion of the Lachlan Fold Belt sampled in this investigation, contain higher proportions of SiO_2 and K_2O than the Devonian rocks. Values for Th and U are generally higher in the Carboniferous rocks, being at or above means in tabulations of world-wide data. On the basis of available chemical data the Nelligen Granodiorite shows more similarities to the Carboniferous granitic rocks than to the Devonian Moruya batholith. The Carboniferous and Devonian granitic intrusions are I-type, indicating igneous source material.

Because of the higher proportions of the heat-producing elements K, Th and U, the Carboniferous rocks generate more heat (cf. equation 1) than the Devonian rocks. Values of heat generation have been determined for 18 sites, based on new chemical data. When combined with published chemical data for 5 sites, heat generations at 22 sites (the Moruya batholith is in both groups) are available. The overall mean value for heat generation at these 22 sites is 2.31 $\mu W/m^3$ (s.d. = 0.51 $\mu W/m^3$). For the Carboniferous rocks (Nelligen Granodiorite included) the mean heat generation is 2.53 $\mu W/m^3$ (s.d. = 0.46 $\mu W/m^3$, n = 13), whereas for the Devonian rocks, with the Nelligen Granodiorite (2.83 $\mu W/m^3$) excluded, the mean heat generation is 1.98 $\mu W/m^3$ (s.d. = 0.39 $\mu W/m^3$, n = 9).

The relatively high heat generation in the Carboniferous rocks along the basement margins of the Sydney Basin could influence seismic velocity through the upper crust. It also apparently influences heat flow through the Sydney Basin, which is high for this portion of eastern Australia, and could thus affect the coal rank within the basin. The pre-Carboniferous intrusions which outcrop near or south of 35°S generate less heat than the Carboniferous rocks — and are south of the relatively high heat flow area and coal rank area between Wollongong and Sydney.

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References

Branagan, D. F., Herbert, C., and Langford-Smith, T., 1976. — *An outline of the geology and geomorphology of the Sydney Basin.* Sydney: Dept of Geology & Geophysics, Univ. of Sydney (for 25th Internat. geol. Congr.).

Brunker, R. L., and Rose, G., 1969. — Sydney Basin 1:500,000 Geological Sheet (Special). *Geol. Surv. N.S.W.,* Sydney.

Bunker, C. M., Bush, C. A., Munroe, R. J., and Sass, J. H., 1975. — Abundances of uranium, thorium, and potassium for some Australian crystalline rocks. *U.S. geol Surv. Open-file Rept,* 75-363: 39 pp.

Chappell, B. W., and White, A. J. R., 1974. — Two contrasting granite types. *Pacific Geol.,* 8: 173-4.

——, and ——, 1976. — Plutonic rocks of the Lachlan mobile zone. *25th Internat. geol. Cong., Field Exc. Guide 13C:* 40 pp.

Clark, S.P., Peterman, Z. E., and Heier, K. S., 1966. — Section 24. Abundances of uranium, thorium and potassium. *In* Clark, S. P. (ed.), Handbook of physical constants. *Mem. geol. Soc. Amer.* 97: 521-41.

Day, J. F., 1969. — Carboniferous system. *In* Packham, G. H. (ed.), The geology of New South Wales. *J. geol. Soc. Aust.,* 16: 178-9.

Doyle, H. A., Underwood, R., and Polak, E. J., 1966. — Seismic velocities from explosions off the central coast of New South Wales. *J. geol. Soc. Aust.,* 13: 355-72.

Dulhunty, J. A., 1964. — Our Permian heritage in central eastern New South Wales. *J. Proc. R. Soc. N.S.W.,* 97: 145-55.

Evernden, J. F., and Richards, J. R., 1962. — Potassium-argon ages in eastern Australia. *J. geol. Soc. Aust.,* 9: 1-49.

Facer, R. A., 1976. — Palaeomagnetism, radiometric age and geochemistry of an adamellite at Yetholme, N.S.W. *J. geol. Soc. Aust.,* 23: 243-8.

——, 1977. — Geochemistry and heat generation in the Durandal Adamellite at Yetholme, New South Wales. *Proc. Linn. Soc. N.S.W.,* 102: 26-35.

——, 1978. — New and recalculated radiometric data supporting a Carboniferous age for the emplacement of the Bathurst batholith, New South Wales. *J. geol. Soc. Aust.,* 25: 429-32.

——, Cook, A. C., and Beck, A. E., 1980. — Thermal properties and coal rank in rocks of the southern Sydney Basin, New South Wales. (Prepared for submission).

Felton, E. A., 1974. — Goulburn 1:250,000 Metallogenic Map, Sheet SI 55-12. *Geol. Surv. N.S.W.,* Sydney.

Frost, D. J., 1977. — The geology of an area east of Danjera Dam. Wollongong: University of Wollongong, B.Sc. (Hons) thesis, unpubl.

Griffin, T. J., White, A. J. R., and Chappell, B. W., 1978. — The Moruya batholith and geochemical contrasts between the Moruya and Jindabyne suites. *J. geol. Soc. Aust.,* 25: 235-47.

Gulson, B. L., 1972. — The high-K diorites and associated rocks of the Yeoval diorite complex, N.S.W. *Contr. Mineral. Petrol.,* 35: 173-92.

——, and Bofinger, V. M., 1972. — Time differences within a calc-alkaline association. *Contr. Mineral. Petrol.,* 36: 19-26.

HUTTON, A. C., 1977. — Geology of an area south-east of Bullio, New South Wales. Wollongong: University of Wollongong, B.Sc. (Hons) thesis, unpubl.

JONES, J. G., MCPHIE, J., and ROOTS, W. D., 1977. — Devonian volcano at Yerranderie. *Search,* 8: 242-4.

JOPLIN, G. A., 1931. — Petrology of the Hartley district. I. The plutonic and associated rocks. *Proc. Linn. Soc. N.S.W.,* 56: 16-59.

KANTSLER, A. J., 1973. — The geology of an area near Bungonia, New South Wales. Wollongong: Wollongong University College, B.Sc. (Hons) thesis, unpubl.

MACKAY, R. M., 1964. — The Yetholme granite. A study in the genesis of potash feldspar megacrysts. Sydney: University of Sydney, Ph.D. thesis, unpubl.

MATSON, C. R., 1974. — Dubbo 1:250,000 Metallogenic Map, Sheet SI 55-4, *Geol. Surv. N.S.W.,* Sydney.

MCILVEEN, G. R., 1974. — Ulladulla 1: 250,000 Metallogenic Map, Sheet SI 56-13. *Geol. Surv. N.S.W.,* Sydney.

——, 1975. — Part 2. A metallogenic study of the Ulladulla 1: 250,000 sheet. *Geol. Surv. N.S.W.,* Sydney: 16 pp.

MUNROE, R. J., SASS, J. H., MILBURN, G. T., JAEGER, J. C., and TAMMEMAGI, H. Y., 1975. — Basic data for some recent Australian heat-flow measurements. *U.S. geol. Surv. Open File Rept,* 75-567: 90 pp.

PACKHAM, G. H. (ed.), 1969. — Geology of New South Wales. *J. geol. Soc. Aust.,* 16: 1-654.

PHILLIPS, E. R., and CARR, G. R., 1973. — Myrmekite associated with alkali feldspar megacrysts in felsic rocks from New South Wales. *Lithos,* 6: 245-60.

POLLOCK, E. N., 1977. — The spectrophotometric determination of uranium and thorium in ores. *Anal. Chimica,* 88: 399-401.

RHODES, J. M., 1969. — The application of cluster and discriminatory analysis in mapping granite intrusions. *Lithos,* 2: 223-37.

ROGERS, J. J. W., and ADAMS, J. A. S., 1969*a*. — 90-E. Abundances (thorium) in common igneous rocks. *and* 90-N. Behavior in metamorphic reactions. *In* Wedepohl;, K. H. (ed.), *Handbook of Geochemistry,* II-4: 90-E-1 — 90-E-12 *and* 90-N-1. Berlin: Springer-Verlag.

——, and ——, 1969*b*. — 92-B. (Uranium) Isotopes in nature; heat production in common rocks. *and* 92-N. Behavior in metamorphic reactions. *In* Wedepohl, K. H. (ed.), *Handbook of Geochemistry,* II-4: 92-B-1 — 92-B-3 *and* 92-N-1. Berlin: Springer-Verlag.

RYBACH, L., 1976. — Radioactive heat production in rocks and its relation to other petrophysical parameters. *Pageoph,* 114: 309-17.

SASS, J. H., JAEGER, J. C., and MUNROE, R. J., 1976. — Heat flow and near-surface radioactivity in the Australian continental crust. *U.S. geol. Surv. Open-File rept,* 76-250: 91 pp.

STEIGER, R. H., and JAGER, E., 1977. — Subcommission on Geochronology: convention on the use of decay constants in geo- and cosmochronology. *Earth Planet. Sci. Lett.,* 36: 359-62.

TOWEY, P. E., 1965. — The geology of Yalwal Creek, Bundundah Creek and Grassy Gully. Sydney: University of Sydney, B.Sc. thesis, unpubl.

VALLANCE, T. G., 1969. — Southern and central highlands fold belt. Plutonic and metamorphic rocks. *In* Packham, G. H. (ed.), Geology of New South Wales. *J. geol. Soc. Aust.,* 16: 180-200.

WALL, V. J., 1965. — The geology of Yalwal south. Sydney: University of Sydney, B.Sc. thesis, unpubl.

WHITE, A. J. R., CHAPPELL, B. W., and CLEARY, J. R., 1974. — Geologic setting and emplacement of some Australian Paleozoic batholiths and implications for intrusive mechanisms. *Pacific Geol.,* 8: 159-71.

APPENDIX I

PETROGRAPHY OF THE SAMPLES ANALYSED

Samples were collected from localities A to C, E to J, L to S, and W (Fig. 1). (Only the designating letter is used in the following description.) Table 3 contains chemical data, and references to published petrographic descriptions. The petrographic descriptions are generally restricted to the samples analysed, except for the rocks near Bullio (N,O,P) (Hutton, 1977) and Yalwal (R) (Frost, 1977) where more general petrographic descriptions are given based on petrographic studies of several thin and polished sections. References in this Appendix are included in the list following the text of this paper.

A. Sample R7577 is a porphyritic granodiorite from the Gulgong Granite (Matson, 1974), with feldspar phenocrysts up to 15 mm set in a groundmass with an average grainsize of 2 mm. The composition is quartz (29%); perthitic potash feldspar (16%); and albite-rimmed plagioclase (44%), with rim myrmekite; biotite (6%), (α = pale brown, $\beta = \gamma$ = dark brown, with apatite and zircon inclusions); and accessory minerals (2%) — magnetite and sphene. Alteration minerals include clinozoisite, chlorite, epidote and "sericite".

B. The Wuuluman adamellite has been described by Phillips and Carr (1973), being distinctive in containing tabular potash feldspar megacrysts up to 75 mm in length, some of whict exhibit rapakivi textures. (The analytical data correspond to the petrography described by Phillips and Carr, 1973.)

C. Day (1969) has described the tuffaceous rocks which outcrop north and northwest of Rylstone. Sample 7585 is a fawn tuffaceous dacite — close to rhyodacite — with feldspar, quartz and lithic fragments up to 3 mm set in a fine-grained groundmass of partly devitrified glass (58%). As noted by Day (1969, p.179), the 5% clear quartz grains are fractured, and embayed, and some small grains have small acicular "overgrowths". The feldspar crystals are also fractured, and consist of both potash feldspar, 10% (sanidine; Day, 1969) and plagioclase, 21% (altered, possibly about An_{35}), occurring both as large grains and in the groundmass. Minor biotite (α = yellow brown, β = γ = dark brownish green), hornblende (α = brown, β = brown green, γ = dark green, with apatite inclusions); magnetite, and zircon are also present. Alteration products include "sericite", hematite, chlorite and calcite. The lithic fragments comprise a sufficiently small proportion that they probably do not significantly influence the chemical analysis, especially as they appear to be similar in rock type to the main rock.

E. The porphyritic rhyolite from this site consists of quartz and feldspar grains (3 to 4 mm across) set in a grey-green aphanitic groundmass and has been termed the "Huntingdale Porphyry" (S. Holland, *pers. comm.,* 1977). Clear, fractured, embayed quartz grains (16%) contain inclusions of rutile and tourmaline. The feldspar grains include cloudy perthitic potash feldspar (19%) and strongly sericitized plagioclase (5%). Magnetite comprises less than 1%. The (59%) groundmass, which may include some devitrified glass (although difficult to identify definitely), contains quartz and feldspars. In addition to "sericite" and clay minerals, alteration has produced epidote and calcite.

F to K. These sites are from various granitic phases of the Bathurst batholith. Vallance (1969) has presented a summary of descriptions of rocks of this batholith, which is a composite suite of massive (undeformed) intrusions ranging from granites to relatively minor mafic phases (the latter not having been sampled in this study).

At Dunkeld (F) a grey, even-grained (3 mm) adamellite outcrops, consisting of 25% quartz with rutile inclusions; 25% perthitic potash feldspar and 40% plagioclase (An_{34}), with rim and bulbous myrmekite; 5% strongly pleochroic biotite (α = brown to straw, β = γ = dark brown) with dark haloes around zircon inclusions; 4% strongly pleochroic hornblende (α = pale brown, β = green, γ = dark greenish brown) ; and 1% accessory minerals (magnetite, spinel, apatite). Alteration products include "sericite", epidote and chlorite.

Descriptions of the Durandal Adamellite (G) have been given by Mackay (1964) and Facer (1977), and of the granodiorite at Hartley (K) by Rhodes (1969). Joplin (1931, pp.23-27) has described in detail the granite at Hartley (J).

The porphyritic adamellite from Sodwalls (H) consists of 24% quartz, with inclusions of rutile and tourmaline; 46% orthoclase (tabular crystals up to 6 mm in length), with ribbon perthite, and altered to "sericite"; 27% plagioclase (An_{36} to An_{42}), altered to "sericite", epidote and minor calcite; 1% biotite (α = yellow brown, β = γ = dark greenish brown) with inclusions of zircon; and 1% hornblende (α = greenish brown, β = brown, γ = dark brown); and approximately 1% apatite and magnetite. Both biotite and hornblende are partly chloritized.

The Carlwood granite (I) is pink, coarse and even-grained (average 4 mm). Quartz comprises 36% and is free from inclusions. Perthitic orthoclase comprises 42%, and albite-rimmed plagioclase 19%, with rim myrmekite. Minor biotite (α = pale brown, β = γ = dark brown), brown to green hornblende and magnetite are also present. Alteration minerals include "sericite", epidote and chlorite.

L. "The Carcoar Granite appears to be discordant" (Vallance, 1969, p.194) with a range in composition which includes granite and quartz diorite. Other Devonian granitic intrusions in the Lachlan Fold Belt are concordant. The sample analysed is a grey, medium-grained (3 mm) granodiorite, and contains 20% clear quartz, 20% perthitic potash feldspar and 45% plagioclase (An_{40} to An_{45}), which may be zoned with sericitized cores. Biotite comprises 10% (α = yellow brown, β = γ = reddish brown) and twinned hornblende 5% (α = pale brown, β = greenish brown, γ = dark green). Magnetite is accessory. Alteration minerals include "sericite" and epidote, and localized clinozoisite and prehnite.

M. The rhyodacite from Yerranderie is strongly altered, with little of the original phenocrysts remaining. It was sampled from drill core, but field relationships are unknown — except that it appears similar to the Bindook Porphyry (cf. Vallance, 1969, p.194). The feldspar phenocrysts are sericitized, and the mafic phenocrysts altered to chlorite. Quartz is abundant.

N to P. The Bindook Porphyry (N) is dacitic to rhyodacitic, and has been subdivided into two members (Hutton, 1977). It contains phenocrysts of embayed quartz (8%) and plagioclase in a fine-grained groundmass of quartz and orthoclase, with minor biotite and hornblende. The plagioclase phenocrysts (26%) are zoned, with cores of An_{34} to An_{54} and rims of An_{20} to An_{25}. Hornblende (α = pale green, β = green, γ = dark green to brown) phenocrysts comprise 4%; and slightly pleochroic hypersthene, clinopyroxene and biotite are also present. Magnetite, zircon and topaz are accessories. Alteration minerals include "sericite" and epidote in plagioclase cores, and chlorite, clinozoisite and prehnite.

The mineralogy of the granodiorite from locality O is similar to that of the rocks from locality N, except that the plagioclase is more calcic (cores of An_{38} to An_{47}) and hypersthene is absent. This granodiorite is non-porphyritic, with grains averaging 2 to 3 mm across.

The granodiorite of locality P is distinct from that of locality O, being coarse-grained, with elongate hornblende phenocrysts up to 15 mm in length set in an even-grained pale grey groundmass. Quartz comprises 13% of the rock, orthoclase 19% and plagioclase (An_{35} to An_{45} cores, An_{20} rims) 40% — with minor myrmekite. The hornblende (α = pale green, β = green, γ = dark green to brown) comprises 20% and biotite (α = pale brown, β = brown, γ = dark brown) comprises 5%. Accessory minerals include magnetite, zircon and apatite. Alteration includes sericitization of plagioclase, especially cores, and chloritization.

Relationships between the rocks at localities N to P will be discussed in a separate presentation by Hutton (in prep.).

Q. The granodiorite at Bungonia (Marulan Granite) has been described by Kantsler (1973), and is the subject of a separate study by P. F. Carr *et al.* (in prep.). Two samples were analysed in this investigation, each being even- and medium-grained (2 to 3 mm), and each containing quartz, potash feldspar, plagioclase and minor mafic phases. Magnetite is the main opaque phase, and is accompanied by minor hematite and ilmenite.

R. Four samples from the small outcrop of the Bundundah granite were analysed, including a fracture zone of hydrothermal alteration about 0.5 m wide. The granite has two phases — an outer pale fawn porphyritic microgranite, (average grainsize 1 mm) and an inner pink porphyritic granite (average grainsize 4 mm) which contains xenoliths of the fine-grained phase. Aplite dykes and hydrothermally altered fracture zones are common, being subparallel to the outer contact of the porphyritic microgranite. These features indicate that emplacement of these two granitic phases was not quite synchronous. The fine-grained phase contains phenocrysts, up to 10 mm, of quartz in an hypidiomorphic granular groundmass of quartz, microcline, plagioclase and minor biotite, apatite, sphene and hematite after magnetite. Lack of quartz phenocrysts is the only major difference between the porphyritic granite and the fine-grained phase. The overall approximate proportions are quartz: 34%, potash feldspar: 42%, plagioclase: 16%, biotite: 4%, and accessory minerals: 5%. In the alteration zone (centred on a sulphide-rich vein) the quartz and biotite contents remain the same, but most of the feldspar is altered to sericitic micas and epidote, and pyrite and chalcopyrite comprise 5%. Although the alteration vein has sharp contacts, the host granite contains sulphides within 5 cm of the vein.

S. The small inliers of granite in Gooloo and Conjola Creeks are exposed below the Permian Conjola Subgroup of the Sydney Basin. In Gooloo Creek the granite is even- and coarse-grained (5 mm), and, although moderately weathered, is fresher than the outcrop in Conjola Creek (S. H. Hickey, *pers. comm.*). Quartz comprises 4% of the granite. The perthitic potash feldspar is heavily clouded by sericitic alteration, and comprises 62%. Plagioclase (An_{44}) is also altered — to "sericite", clay and calcite — and comprises 27%. Biotite (α = yellow, $\beta = \gamma$ = dark brown) and weakly pleochroic hornblende (brown and green) each comprise 3%. Magnetite and sphene are very minor accessories.

W. One of the phases of the Moruya batholith is the tonalite analysed here. Sample R6472 is a grey, even- and medium-grained (2.5 mm) tonalite which contains xenoliths, although xenolithic material was avoided during preparation for analysis. Quartz comprises 11% of the tonalite and contains rutile inclusions. Potash feldspar (21%) and plagioclase — An_{37} — (53%) are the main constituents, with 9% zircon-bearing biotite (α = yellow brown, β = brown green, γ = dark green brown) and 5% twinned hornblende (α = yellow green, β = green, γ = dark green) being the ferromagnesian minerals. Magnetite, sphene, apatite and zircon make up the accessory minerals. Alteration products include minor "sericite", chlorite and epidote.